MINOR STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF CORNELL UNIVERSITY

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XXVII. SIMPLICITY VS. COMPLEXITY OF COLOR HUES

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In the experiments here reported, we have sought to obtain introspective evidence with regard to the alleged compositeness of color hues. The opinions of psychologists and color-theorists concerning the existence of composite colors may roughly be classified into three groups. (1) All colors, with the exception of black, white, red, yellow and blue are composite; orange, for example, is composed of red and yellow; green is composed of blue and yellow. (2) In addition to the simple colors of the first group, green is also simple. It is true that green may be obtained by mixing blue and yellow pigments; but still it is a quality which is neither blue nor yellow; and it cannot, therefore, be factored into blue and yellow. All other colors, however, are composite. (3) No colors are composite; all colors are psychologically simple. The psychological orange may be obtained by a psychophysical mixture of red and yellow, but the resultant quality is simple; however *like* red and yellow it may appear, it cannot be analysed into these two components. Bentley has shown that this disagreement is partly a result of different methods of analysis, partly of a confusion of the psychological and the psychophysical points of view.[1] In this paper we shall avoid, so far as possible, all theoretical considerations: if our problem has any relation to color-theory, it is indirect; and all arguments from qualitative opposition, color-mixture, contrast, color-blindness, etc., are beside the point. We are concerned solely with psychological (not logical, psychophysical, physiological, physical, or technical) analysis of color hues.

It has been pointed out above that those who believe in the existence of composite hues do not agree among themselves, and that their disagreement turns on the character of green. The principal advocate of composite green is Brentano.[2] He approaches the problem phenomenologically; he thinks that he can see B and Y in green; and he calls to witness Goethe and many other persons, especially painters, who are assumed to be especially skilful in the analysis of colors. With his position Holt[3] is in agreement. This view means that if all the hues between Y and B are arranged in a series, they fall on a single straight line, and G lies about the middle; just as O lies in the middle of the R-Y series. Katz[4] argues against the position on the ground that the two series, when directly compared, are not in all respects similar; a hue, for example, which lies in

[1] M. Bentley, The Simplicity of Color Tones, *Amer. Jour. Psychol.*, xiv, 1903, 92 f.

[2] F. Brentano, *Untersuchungen z. Sinnespsychologie*, 1907, 1 ff; 129 ff.

[3] E. B. Holt, The Place of Illusory Experience in a Realistic World, in *The New Realism*, 1912, 333 ff.

[4] D. Katz, *Die Erscheinungsweisen der Farben*, 1911, 276 f., 360 ff.

the B-Y series near the Y appears greenish, not bluish; while a hue occupying a similar position in the R-Y series appears not orangeish but reddish. Furthermore, it is not true that painters are more skilful in the psychological analysis of color than are psychologists themselves. The two professions have different points of view; when the painter analyses a color, his problem is to determine what pigments will reproduce that color on his palette; he, therefore, 'sees' in a given hue the colors of its pigment-components; while the psychologist sees hues which are similar to other hues.

The painter, now, would willingly accept the challenge to reproduce the seen color from the 'seen' components. Brentano also, if we take him at his word, would accept this challenge. "Die Aehnlichkeit, die Orange einerseits mit Rot und anderseits mit Gelb hat, ist nicht derjenigen zu vergleichen, die etwa einem Ton zwischen *c* und *e*, z.B. dem zwischen ihnen gelegenen *d*, mit jenem tieferen und diesem höheren Ton zugeschrieben werden kann, sondern offenbar derjenigen, welche der Zweiklang *ce* mit den beiden Komponenten zeigt. Man erkennt darin die beiden Farben, wie man dort die beiden Töne heraushört."[5] Composite colors are fusions, then, similar to tonal fusions, and may be analysed in the same way. We may suppose, therefore, that as in the analysis of the tonal fusion *ce* we come out with two tones, which may be named by their vibration frequencies, and which when produced together will reproduce the original fusion, so in the analysis of a color fusion we should be able to name or point out the components, and thus to reproduce the original fusion. The obvious test is recourse to experiment.

We know of only two attempts to attack the problem experimentally. Katz[6] reports an experiment with 80 school-girls, 8-9 years of age, who presumably had no knowledge of color-mixing, but who named the colors correctly. They were unable to analyse successfully either orange or green, although they had been shown how a violet could be obtained by mixture, and although in most cases they were clever enough to avoid choosing the same pairs of components in both cases. Mrs. Ladd Franklin,[7] who has long contended that R, Y, G and B are 'psychically unitary,' and that the intermediate colors are non-unitary colors or 'color-blends,' has devised an experiment, the results of which, she thinks, proves her position. She has not published her results in detail, however, and we have deemed it advisable to repeat her work. Her method will be discussed, later, in connection with our own results.

Those psychologists who believe in the simplicity of color hues contend that what their opponents 'see' in colors is only a *likeness* to other colors; that O, for example, is *like* R and *like* Y, not that O *is* R and Y. Bentley long since pointed out that the colors about the base of the color pyramid fall into two major groups; "the one contains the reds and yellows, the other the greens and blues. Within each group there is a special kinship which marks off one group from another."[8] Katz, who is very cautious as regards the com-

[5] *Op. cit.*, 16.

[6] *Op. cit.*, 366 f.

[7] C. L. Franklin, Determination of the Psychically Unitary Color-Sensations, Report of the Philadelphia Meeting of the Amer. Psychol. Asoc., *Psy. Bull.*, xii, 1915, 62 f.

[8] *Op. cit.*, 92 f. H. E. Houston and W. W. Washburn *Amer. Jour. Psy.*, xviii., 1907, 523) find no overlap of the names B and Y, and argue from this fact that the two colors cannot be visible in G.

posite nature of O and V, remarks that in his experience G has a similarity to the colors Y and B which is greater than that existing between G and R. In Westphal's experiments, where among others the best G (*Urgrün*) was determined, Katz reports as observer that the same stimulus appeared *successively* bluish and yellowish; but, he adds, "die spurenweise Andeutung der Nachbarfarben in den Urfarben, wie sie bei dieser Einstellung vorhanden ist, ist natürlich von ganz anderer Art als das Enthaltensein je zweier Urfarben in den zwischen ihnen liegenden Farbentönen, z.B. des Rot und Gelb in dem Orange."[9] What this difference is he does not say; he thinks that the brightness and the feeling-tone of G lie midway between those of B and Y (the same thing might be said also of R); but he does not commit himself with regard to the composite character of O and Y. Westphal found that, in the determination of *Urfarben* (e. g., *Urrot*), it is not always possible for the observer to fix the point where the hue concerned does not evince a close relation to the neighboring hues (*weder gelblich noch bläulich erscheint*). If, he continues, Brentano concludes that the sensation green is a sensation yellow-blue, because some persons can see Y and B in it, then with equal right one may conclude that the sensation R is yellow-blue, and the sensation Y is red-green.[10]

In view of this divergence of opinion, we (1) planned an experiment which we hope is without prejudice, and which is purely analytical in its nature; (2) we have repeated Mrs. Ladd Franklin's experiment; and (3) we have performed a variant of Westphal's experiment. The procedure of these three experiments, together with their results, will be taken up in order.

Experiment I

The object of this experiment was to test the observer's ability to analyse colors, and to compare the results with those of observers who selected colors which were 'like' the stimulus. We employed as stimuli the following colored papers, all of the best available chroma and medium tint: R, O, YO, Y, YG, G, BG, B, V, P; and, in addition, both light and dark tints of O, G, V, and a medium tint but poor chroma of O, G, B and V. The O was taken from the Milton Bradley Co.'s Pure Spectrum Scales; all the other stimuli were Hering papers. The tints and lesser chromas were obtained by mixing in the requisite amounts of Bk-W.

The observer sat at a table facing a screen. The screen had a square window, which could be closed by a shutter. Immediately behind the screen stood a color-mixer, upon which the various stimuli were shown. On the table before the observer was a tray of sample colors, 3 x 6.5 cm., mounted on grey cardboards of slightly larger size. These color samples, 130 in number, were representative of the entire color circle with varying hues, tints and chromas, and also included a few greys.

When the stimulus was presented, the observer was asked the following question: "Does it appear simple (homogeneous), or do you see other colors in it?" In case he reported 'simple,' he was asked: "Is it like any other color?" If the answer was 'yes,' he was then

[9] *Op. cit.*, 363.

[10] H. Westphal, Unmittelbare Bestimmungen der Urfarben, *Zeit. f. Sinnesphysiol.*, xliv, 1909-10, 198, 230 n.

instructed: "Choose (from the samples) the colors which it is like." But if the answer was 'no,' he was asked to name the presented color, and the experiment came to an end. If, however, in answer to the first question, the observer found 'other colors' in the presented color, he was then instructed: "Choose (from the samples) the colors that you see." When this had been done, he was asked to name the colors he had chosen, and also to name the stimulus color.

After the experiments had progressed for some time it seemed advisable to reduce the number of stimuli by striking out the YO, the P, the light and dark tints, and the lesser chromas, since these colors did not yield results sensibly different from the others. In the experiments which we shall report, therefore, we employed eight stimuli, all of the best possible obtainable chroma. We had twenty-three (in some cases twenty-four) observers. About half of the observers had had some training in psychological observation; some were instructors in psychology, others were students in the psychological laboratory; of the other half, four were girls, 12-15 years of age, who had had some experience with mixing pigments, and the remainder were college students taken at random. We give the results in Table I. In preparing the table we have grouped the colors which were chosen as 'likes' or as 'components' into 19 classes, represented by the color symbols at the head of the vertical columns; e. g., the column R contains all the hues which were distinctly red (neither bluish nor yellowish), but which differed in chroma, tint, texture, etc. We have classified the observers into trained (Tr) and untrained (Un), and also according to the nature of their judgments (simple or composite). The Table, then, shows the distribution of the colors chosen by each of the two classes of observers, and according to the two types of judgment. It should be remarked that, in the instruction given, there was no limit to the number of colors which an observer might choose as 'like' the stimulus or which he might 'see in' the stimulus; the sum of the numbers on a horizontal line is therefore often greater than twice the number of observers.

There are three gross results. (1) The judgments of likeness and of composition of color hues can be made, and are made, by all observers, trained and untrained. But, in general, the choice of components shows practically the same distribution as the choice of likes; so that the basis of judgment in the two cases is perhaps similar, if not identical. (2) Only in exceptional cases are R, Y, G, and B reported as components of (or as like) the stimulus color. The principal exception is that, when one of these colors is itself the stimulus, it is most 'like' itself, or is 'composed of' itself. In the case of intermediate colors, O, YG, BG, and V, the tendency of distribution is *not to reach* the corners of the color square. (3) There is evidence, in judgments both of simplicity and of complexity, that the observer tends to restrict his choices to a single side of the color square. Thus in the case of intermediates the distribution is approximately symmetrical, whereas in that of the corner colors the tendency is for the judgments to occur only on the one side; this latter tendency is greater for R and Y than for G and B.

It seems to us that, in the face of these results, but one conclusion is possible; that, whatever some of our observers saw in the stimulus, they did not see component colors. So far as this experiment goes, our results are totally at variance with the view that the intermediate colors are fusions or blends, comparable with tonal fusions. Further-

TABLE I

Stim.	No. of Obs.	Judgment	VR	R	OR	RO	O	YO	OY	Y	GY	YG	G	BG	GB	B	VB	BV	V	RV	Bk-W
R	7 Tr	simple		6	3	1		1	2												
	7 Un	"		6	1	1				1											
	4 Tr	composite		2	2	1		1	1												
	5 Un	"		3	1			1	1	1								1			2
																					2
O	9 Tr	simple			4	1	8		4	1											
	6 Un	"				1	6	1													
	3 Tr	composite			1	2	1		2												
	6 Un	"		1	2	1	3	1	1	2	1										
Y	6 Tr	simple							1	7	3	1									
	9 Un	"							1	6	1	3									
	5 Tr	composite								6	4	3									
	3 Un	"								3	1					1					
YG	6 Tr	simple								2	1	7	1								
	4 Un	"									3	4									
	5 Tr	composite								4	1	5	3								
	8 Un	"								4	4	3	3			1					
G	10 Tr	simple								2	1	3	9	2					2		
	4 Un	"										1	3								
	1 Tr	composite											1								
	8 Un	"								3	3		7	1							2
																					1
BG	6 Tr	simple									1		1	6	1						
	5 Un	"												7	1				1		
	6 Tr	composite										2	2	3	2	1	1				3
	7 Un	"								1			1	5	4	1					
B	11 Tr	simple										2	2			11	2		1		
	10 Un	"												1	1	11	1		1		
	1 Tr	composite														1					
	2 Un	"	1													2					1
V	7 Tr	simple	1	3					1							1	2	1	5	1	
	6 Un	"	1														3		5	2	
	5 Tr	composite	2	1												1	1		3		2
	6 Un	"	2	1	1												2	1	4		

more, as regards the question of the composite character of green, we point out: (1) that the distribution of choices, whether of similars or of components, conforms to the type of distribution for the other corner colors; (2) that in no case is a blue or even a greenish blue chosen as a component of G; and (3) that those who 'saw other colors' in the stimulus most frequently chose, as components, colors which belonged to the same group as the stimulus. These facts all tell against the composite character of green.

Finally, we remark that, on the basis of similarity, or because some observers can see other colors in them, the corner colors themselves, B alone excepted, might be regarded as composite. It is true that we employed colored papers, which are notoriously impure; but then pigments are also impure; and our results are in accord with those of Westphal, who employed spectral lights as stimuli.

Experiment II

We thought it well, at this point, to repeat Mrs. Ladd Franklin's experiment. The only published account of her method and results is as follows. "By exhibiting at once (say) seven colors, on discs rotated by a common electric motor, made practically equal in intensity and saturation but just noticeably different in color tone, it is found that all observers can distinguish between the unitary colors and the color blends. The judgment is a perfectly easy one to make; none of our observers failed to make it save one, and he turned out to have dichromatic vision—which involves of course the impossibility of ever seeing a color blend."[11] We have supplemented this meagre account of method by written notes taken from Mrs. Ladd Franklin's verbal report at the Philadelphia meeting. The experiment as we performed it was as follows. In a first series, we set up seven compound discs which, when rotated, gave a series of colors practically equal in tint and chroma but just noticeably different in hue, passing from a bluish red through red to a yellowish red. In a second series, the hues ranged from a reddish blue through purple to a bluish red; and in a third series, from a yellowish red through orange to a reddish yellow. The instruction for the first series was: "Pick out a color which is neither bluish nor yellowish. Which colors are bluish? which colors are yellowish?" The instruction for the second series was the same, except that 'reddish' was substituted for 'yellowish.' When the results from this instruction (which was Mrs. Ladd Franklin's) had been obtained, we supplemented the instruction by asking: "Which colors are unitary? Which are complex?" In the third series we further modified the instruction by asking the five questions: "Which colors are yellowish, which are orangeish? Which are reddish? Which are complex? Which are unitary?" There were 16 observers, four of whom were trained, six were taking their first course in the laboratory, and the remaining six had had no experience in psychological observation. The results appear in the following Tables, which show the distribution of the judgments for each one of the seven discs.

[11] *Op. cit.*, 63.

TABLE II

SERIES 1

BR——			R			——RY
Number of disc.....	1	2	3	4	5	6	7
Bluish.....	16	16	8	.....	.....	.....	.....
Neither B nor Y....	.....	.....	8	13	2	.....	.....
Yellowish.....	.....	.....	.....	4	15	16	16
Complex.....	10	11	8	6	8	12	11
Unitary.....	6	5	8	10	7	4	5

SERIES 2

BR——			P			——RB
Number of disc.....	1	2	3	4	5	6	7
Bluish.....	15	16	15	10	8	7	6
Neither B nor R....	1	.....	1	5	2	.....	1
Reddish.....	3	4	6	9	13	15	14
Complex.....	4	8	8	10	10	10	6
Unitary.....	12	8	8	6	6	6	10

SERIES 3

YR——			O			——RY
Number of disc.....	1	2	3	4	5	6	7
Yellowish.....	6	5	6	8	13	16	16
Orangeish.....	5	7	9	13	14	7	4
Reddish.....	16	15	14	13	8	3	2
Complex.....	7	9	8	8	10	9	4
Unitary.....	9	7	8	8	6	7	12

These results, we suppose, would have been satisfactory to Mrs. Ladd Franklin,—had we not asked for judgments of unitariness and complexity! As they are, they do not bear out her conclusion that "all observers can distinguish between the unitary colors and the color blends." Of the 16 observers, 6 regard red as complex, and 5 find neither red nor blue in purple. A still more curious result is that for O in the 3rd series: 13 see it as reddish, 13 as orangeish, but only 8 see yellow in it, and only 8 see it as complex; evidently, some persons do not see yellow in orange, and some see orange as unitary. Such examples might be multiplied; but it is obvious that, although the form of the curves for bluish, neither bluish nor reddish, and reddish might be satisfactory to Mrs. Ladd Franklin, the fact that *on the average only one-half of the observers regard the colors in the R-B series and in the R-Y series as complex* does not square with her logical conclusion that resemblance implies common character, and that since purple (for example) resembles both R and B, it must therefore be psychologically a color blend. Because

of this confusion of the logical and the psychological methods of analysis, the method of this experiment is inadequate to the problem; and for the same reason the results are at variance with those of our first experiment.

Experiment III

In this experiment we attacked the problem of the compositeness of green by a metric method. We prepared discs of blue-green and yellow-green, which were not so far removed in the color series but that, by the second law of color mixture, their mixture gave a green of good chroma. With a preponderance of the BG the mixture was decidedly bluish; and with an excess of YG the mixture was distinctly yellowish. The problem was to determine the points of change on the one hand between blue and not-blue, and on the other hand between yellow and not-yellow. The method employed was that of Constant Stimuli. Five stimuli were selected, with intervals of 3°. These were arranged by hazard into 100 series, so that 500 observations were made under each instruction. In the first experiment the instruction was: "You are to judge Bluish or Not-bluish." The observer was told, emphatically, that 'not-bluish' did *not* mean yellowish or greenish or pinkish; it meant not-bluish and nothing more; he was also urged to make every effort to keep his attitude constant throughout the experiment. In the second experiment the categories were 'yellowish' and 'not-yellowish,' and the observer was further instructed as in the first experiment. We hoped, by thus formulating the instructions, to accomplish two things: (1) to eliminate the question of green entirely (it will be apparent that only by implication can 'green' come into our final results), and (2) to discover whether or not it is possible, under experimental conditions, to carry a single attitude ('bluish' or 'yellowish') through the Blue-Yellow series. We believe that on both counts we have weighted the experiment, if at all, in favor of Brentano's contention. The observers were Dr. L. D. Boring (L. D. B.), Dr. W. S. Foster (F), Dr. E. G. Boring (B), and Miss M. E. Wright (W), a student in quantitative psychology. The first three observers have had long experience in psychological observation. Only the last two, however, were able to complete the entire series; and although the others completed the preliminary series and proceeded far enough in the experiment proper to give an indication of the final outcome, we shall not consider their quantitative results. In the Table which follows the value of RL equals degrees of YG.

TABLE III

		RL	h	Interval btwn. Y and B
Obs. B.	Bluish or not.....	87.868	.1669	12.627
	Yellowish or not.....	75.241	.1640	
Obs. W.	Bluish or not.....	44.868	.1092	17.024
	Yellowish or not.....	61.492	.1315	

These figures mean that, for both observers, the blue-yellow series is neither blue nor yellow throughout its course: there is a point (in the sense of a limen) where blue changes to not-blue, and an-

other point where yellow changes to not-yellow. There is a difference, however, between the two observers. For B. the blue and yellow areas cross each other; or, to put it in another way, there are in the B-Y series (1) an area that is bluish but not yellowish, (2) an area that is *both bluish and yellowish,* and (3) an area that is yellowish but not bluish. For W., on the other hand, the two extreme areas do not meet; there is an intermediate area that is *neither bluish nor yellowish.* It is clear that either result is fatal, so far as this experiment goes, to Brentano's notion that all colors between blue and yellow are components of these two extremes.

While, as has been said, the other two observers did not complete their series, the results obtained agree in principle with those of W. The intermediate interval (neither bluish nor yellowish) for F. was about 21°, for L. D. B. about 16°. The introspections also show that these three observers had difficulty in carrying their instruction through the region of green. W. says: "About the middle of the series, judgments of yellowish and bluish are difficult. . . . Green is so pronounced that it is hard to say whether the color is yellowish or bluish." L. D. B. reports: "I think of the color series from Y to B through G as a straight line, and I attempt to place the stimulus in position with reference to that series. . . . There are times when, disregarding my *Aufgabe,* I asked myself 'Is it yellowish or bluish green or just a good green?'" F. also reports: "Sometimes visual images of the spectrum come up, particularly the green and yellow parts; green is seen in such cases. The chief processes are auditory kinaesthetic words; but besides these visual image of true green, and (rarer) a visual image of yellow." B., on the other hand, was frequently influenced in his judgment by secondary criteria, and perhaps on this account was better able to disregard the insistency of green. He says: "The judgment 'yes' (Yellowish) is a positive reaction on my part to the stimulus; the yellowish hue is somewhat alive, keen, sharp, bright, not smooth, not uniform; early in the experiment I wondered whether yellowish might not be a slight painful complex in the eyes. The judgment 'no' (Not-yellowish) is an equally positive passive acceptance. The presentation is smooth, comfortable, quiet, calm; I don't know how much of this is my reaction, and how much is immediately inherent in the color. . . . The blue was soft and comfortable as against the blare of the yellow; all a matter of eye pressures and pains."

The color experience in these experiments did not always appear simple. Three of the observers occasionally reported a 'haze' over the color; for W. and F. this was yellowish, and influenced their judgments. B., who has given the most complete account, says: "Sometimes I think I see spots that are more bluish than others or perhaps are even blue; sometimes these spots give the impression of seeing the disc through a bluish haze; sometimes the spots or haze seem to come and go as if due to a fluctuation of attention or determination. The vagueness of this haze makes me wonder whether it is a haze at all, or whether it is not a shifting underdetermination to a tied image, like a memory-color." "In general the 'yes' hue was complex, whereas the 'no' hue was simple. I mean that in taking the hue as yellowish I never took it as yellow, but always as if yellow were a part of it. The 'not-yellow' was always just something that belonged all together, seldom green or blue, but smooth. I do not know what the nature of the yellowish component is. I should guess that it is either my organic reaction to the stimulus or something like a memory-color which, under this

determination, spreads over the disc or at least spreads over it intermittently. The intermittence does definitely occur; in case of hesitation the hue is now yellowish (complex), and now just something else (a simple green or yellow green). I have thought that this intermittence was exactly like the intermittence that one gets in hearing out the components of a clang."

Conclusions. The results of our first experiment bespeak the simple character both of the intermediate colors and of green; and those of the third experiment also conflict with the alleged composite character of green. The results of the second experiment are equivocal because of inadequacy of method. The results of the first and third experiments are unequivocal; however 'like' a hue may be to neighboring hues, it apparently cannot be resolved by purely psychological methods into these hues as 'components.'

Secondly, the experiments seem to show that, when an observer thinks he 'sees other colors' in a stimulus, he is really perceiving a resemblance to other colors.

Thirdly, a new problem emerges. One does not simultaneously see R and Y in O; the two similarities appear successively, and only with a shift of attitude. There is evidence that the shift of attitude brings with it something more than a shift of clearness, and further experiments must be made to determine what this 'something more' may be.

Fourthly, we find, as Westphal found, that of all hues B is most like itself. The roughness of our materials is, we suppose, at any rate partly responsible for our failure to get a definite confirmation of Westphal's further rank-order: Y, G, R. But it is clear that Westphal's psychological interpretation of individual differences in the determination of *Urfarben* should be put to the test of further experiments.[12]

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[12] Westphal, *op. cit.*, 198, 213 ff. From the phylogenetic point of view, there is a certain plausibility in the hypothesis that B and Y are the only psychologically pure colors, and that R and G are psychological compounds of B and Y. No one, however, so far as we know, has maintained the composite character of R, although the structural likeness of the series B-R-Y and Y-G-B might logically have suggested it. Moreover, the argument from phylogeny must always, in matters of psychological observation, be secondary; the question of this paper, as we said above, is psychological and not biological.